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Measurement agreement between two activity monitors and a self-report recall measure under free-living conditions

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Measurement agreement between two activity monitors and a self-report recall measure under free-living conditions

by

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Signatures have been redacted for privacy

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This thesis is dedicated to the participants in the study,

to my friends in the Health and Human Performance Department at Iowa State University,

to the members of my POS committee,

to my family and friends,

to my parents Pelusa and Miguel and my siblings for their love and support over the years,

and especially to my beloved wife Gaby for always being there for me.

ABSTRACT

The available methods of assessing PA and energy expenditure (EE) under free-living conditions have shown limitations; therefore, the development of new tools is a necessity.

Purpose: 1) The purpose of this study is to evaluate the agreement of two pattern recognition monitors during a variety of free-living activities, including at least 30 min. of moderate and vigorous PA and 2) to evaluate the ability of participants to recall information about the physical activity that they performed using a physical activity recall instrument.

Methods: 20 participants (mean age 29.9± 5.7) wore the Intelligent Device for Energy Expenditure and Activity (IDEEA) and Armband (SP2) monitors during a whole day (2 trials). The following day, a physical activity recall interview (24PAR) was administered to each of the participants. During one of their two trials the participants were asked to record their activities in a diary.

Results: The IDEEA, SP2 and 24PAR yielded similar total EE estimates (1990±557, 1928±539 and 2092±650 kcal/day, respectively) but estimates of PA were more variable (149.9±78.5, 170.3±74.8 and 111.5±73.2, respectively). The 24PAR estimates of EE and PA were significantly different compared to the IDEEA ($P<0.05$) and SP2 ($P<0.01$); however the effect sizes were small. Correlations among the three instruments were high for total EE ($r=0.81$ to $r=0.91$), but lower for PA estimates ($r=0.59$ to $r=0.14$). No differences were observed when comparing diary vs. non-diary trials for total EE but correlations for PA measures were higher for the diary trial. Correlation values for total sitting time between estimates from the IDEEA and 24PAR were high ($r=0.81$, $P<0.0001$).

Conclusions: the SP2 was found to be a valid instrument to measure total EE and PA under free-living conditions. The 24PAR showed to be a valid tool to measure total activity and sitting time. In this study, the use of a dairy to improve recalls accuracy proved to be helpful only when recalling minutes of PA.

CHAPTER I- INTRODUCTION

The importance of physical activity (PA) for good health is well established (32). However, more accurate assessments of PA are needed to better understand population surveillance, the specific amounts of PA necessary to attain health benefits, the factors that influence PA behaviors and to properly assess interventions promoting physical activity (32, 33). The variation and complexity of individual lifestyles necessitate the development of tools that can accurately measure PA in free-living conditions.

The available methods of assessing PA and energy expenditure (EE) in free-living conditions each have limitations. Self-report techniques allow assessments on larger samples with lower financial costs, but limitations include the misinterpretation of questions by the participant and challenges related to recall of activity. Pedometers are inexpensive objective measures of locomotor behavior; however, they are incapable of recording non-locomotor movements and also lack the ability to record the intensity of movement (33). Activity monitors are non-invasive objective indicators of body movement, but have not been shown to be effective for capturing free-living activities that may involve upper body movements (36). While each of the measures has some utility, the lack of a true criterion measure in the field has made it difficult to determine the best approach for different applications to identify sources of error that could be addressed in future research.

The recent development of a novel device known as the Intelligent Device for Energy Expenditure and Activity (IDEEA) may provide an appropriate criterion measure for field based research. The IDEEA is a portable device that consists of five small motion sensors attached to the chest, thighs and feet, and a microcomputer that receives the output signals from the sensors. The IDEEA device has been shown to accurately detect onset, type, intensity and duration of PA, as well as gait type during laboratory testing (39), and can provide highly accurate estimates of EE under free living conditions (38). However, the device is not without limitations as it is very expensive (~ $4,000) and too "invasive" for monitoring over prolonged periods of time.

The SenseWear Pro2 Armband (SP2) (Body Media, Pittsburgh, PA) is another new monitoring device that is designed to assess PA and EE under free-living conditions. Worn on the dominant upper arm over the triceps muscle, the SP2 is designed to monitor "various physiological and movement parameters" (13). The SP2 contains multiple sensors that collect different physiologic data that helps objectively assess levels of PA and EE. The SP2 is noninvasive and with similar financial costs to accelerometers (~$400). In a recent study, the SP2 was found to provide valid and reliable estimates of EE at rest and reasonable estimates of EE on a cycle ergometer (13). In another study, the SP2 yielded more accurate estimates of total EE at most speeds compared to 4 other PA monitors (CSA, the TriTrac-R3D, the RT3 and the BioTrainer-Pro) (15). The integration of multiple sensors and the use of pattern recognition software may contribute to the favorable results being reported with this monitor.

To date, few studies have evaluated the validity of the IDEEA or SP2 monitor under free-living conditions. In a recent study in our laboratory (37), outputs from the IDEEA and the SP2 were found to be highly correlated and to yield similar estimates of PA and EE. However, the participants in this study did not perform enough moderate or vigorous physical activity (MVPA) to fully evaluate the relationship between these devices. Differences in agreement between the two devices also varied by the type of activities that were performed (range: r=0.59 to 0.92). The IDEEA monitor provides a report of different activity codes that are detected but it was not possible in the past study to determine the types of activities that elicit specific codes on the IDEEA monitor. Therefore, additional research on the utility of the SP2 armband is needed.

The primary purpose of this study was to further evaluate the agreement between the IDEAA monitor and the SP2 during a variety of free-living activities. Participants in the study wore both devices during their active day (early morning until bed time) during two trials, involving at least 30 minutes of moderate to vigorous physical activity. All the participants were asked to supplement their monitoring by completing a detailed diary of their activities in a prospective manner throughout one of the monitoring days. The diary provided information about what the participants actually did during the day. This information would help differences in agreement between the IDEEA and the SP2 to be better understood.

A secondary purpose of the study was to evaluate the ability of participants to recall information about the physical activity that they performed. True validation of self-report measures have been challenging due to the lack of a gold standard measure under free-living conditions (20). We supposed that direct comparisons between the IDEEA/ SP2 monitors and the self-report recall measure used in this study would allow sources of error in these estimations to be determined. To obtain data for this component, all participants were asked to complete a detailed 24-hour recall (24PAR) of their activity upon returning the monitors the next day. The validity of the 24 -hour recall tool was determined by comparing EE estimates from the 24-hour recall data with the data from the IDEEA and SP2 monitors. Comparisons were also made between the diary trial and the trial where no diary was completed to determine if recall accuracy was improved with the inclusion of the diary.

CHAPTER II- EXTENDED LITERATURE REVIEW

Assessment of Physical Activity under Free-living Conditions

The importance of having a physically active lifestyle has been previously discussed (32). The recommended amount of PA for prevention of chronic diseases in adults has been defined by the CDC and the American College of Sport Medicine (ACSM) as 30 minutes or more of moderate-intensity physical activity on most if not all days of the week (27).

Physical activity (PA) has been defined as "any bodily movement produced by skeletal muscles that results in caloric expenditure" (8). Following this widely accepted definition, PA could also be classified into different categories, such as leisure time physical activity, exercise, occupational work, household tasks and transportation. Different activity types have different metabolic costs depending on the activity's intensity. Furthermore, the thermic effect of PA is in general, the most inconsistent component of the daily EE and, depending on the type, intensity and duration of the activities could change significantly from day to day in any given individual.

The need for more accurate methods to assess PA in free-living conditions has also been previously established (4, 11, 13, 15, 33). A variety of methods are available for assessing PA and EE in free-living conditions but each of the methods has inherent limitations (4, 12, 33). Self-report techniques are prone to misinterpretation of questions by the participants, and have reliability and validity problems related to recall of activity. Pedometers are incapable of recording non-locomotor movements and also lack the ability to record the intensity of movement. Direct observation techniques require discipline and practice for accurate coding, could be expensive and time consuming. Doubly-labeled water technique allows for estimation of EE, however, is an invasive measure, does not assess patterns of PA, and has high relative costs (9).

Accelerometry based physical activity monitors (accelerometers) have emerged as one of the most promising measures of PA. Accelerometers are small devices typically wore on the hip, that provide objective measures of overall body movement (29, 36). A major advantage of accelerometers is that they can collect data with minimal intrusion and effort required by the participants. The accelerometers' ability to store large amounts of data allows researchers to obtain detailed information (commonly, minute by minute) about activity patterns over long periods of time. Most accelerometers also provide computer software to download collected data from the device to the computer.

While accelerometers have been frequently used in a variety of research applications they still have some major limitations for assessing PA and EE in free-living conditions (36). However, several new devices employing more advanced technology have recently showed promising results for assessment under free-living conditions. The purpose of this literature review is to summarize the advantages and limitations of accelerometry-based physical activity monitors as a physical activity assessment tool. The potential advantages of newer technologies designed to recognize patterns of movement instead of the amount of movement (6, 24) will also be described.

Background on Accelerometry-Based Activity Monitors

Accelerometers are motion sensors capable of detecting acceleration and deceleration in different planes of movement. Accelerometry-based activity monitors can be unidimensional or uniaxial (usually vertically oriented), bidimensional or biaxial, and three-dimensional or triaxial, depending on the number of motion sensors they possess. Therefore, the monitors can be sensitive to accelerations in one (uniaxial), two (biaxial) or three (triaxial) dimensions.

Monitors also use different processing and filtering techniques that prevent direct comparisons between monitors.

The validity of accelerometry-based activity monitors has been investigated under both laboratory (4, 14, 25, 28, 31, 34, 35) and field conditions (4, 7, 12, 16, 17, 25, 28, 29, 31, 35). Under controlled conditions, several studies suggest that EE can be predicted with acceptable accuracy (10, 26, 34). However, several studies have reported the difficulties of accelerometers measuring PA in the field (4, 7, 12, 35). The inherent problem appears to be that application of laboratory equations is not appropriate for use in field settings. The activities that people perform under free-living conditions are more diverse than the standardized activities performed in a laboratory (e.g. treadmill walking and running at steady state). Because accelerometers are not equally sensitive to all free-living activities there are considerable errors that result from the application of laboratory equations. Investigators have used nature of movement under free-living conditions, particularly for light and vigorous activity (25), and resulted in overestimation in EE.

One of the most noticeable limitations of accelerometers is the underestimation of EE in activities that involve upper body extremity movement such as pushing and carrying objects. This occurs because waist worn monitors cannot capture the movement and associated energy cost of upper body movements. However, locomotor activities represent the majority of daily activities for adults so this may not be a big problem (36).

The inability to detect changes in EE associated with carrying a load and walking on incline planes are also limitations of accelerometry-based activity devices (4, 12, 31). Another validity issue of activity monitors is whether the data collected by the monitor really represents normal activity patterns of the participant or the patterns influenced by the use of the device (36).

Despite these limitations, accelerometers are among the most effective ways to monitor PA in the field. They are objective, easy to use and well tolerated by research participants. However, the limitations need to be overcome to continue to improve PA assessments. The next section will highlight some of the new technologies that have recently been developed to overcome some of these limitations.

New Technologies for Assessing Physical Activity

The detection of patterns of movement instead of amount of movement is one of the most significant advances in tools designed to assess PA. The advantage of this new approach is that movement patterns of PA can be recognized and tracked, rather than estimated using acceleration values.

SenseWear Pro2 Armband (SP2)

The SenseWear Pro2 (SP2) Armband (BodyMedia, Pittsburgh, PA) is a wireless multi-sensor monitor designed to estimate EE and levels of PA in a variety of settings, especially under free-living conditions. The SP2 is worn on the back of the upper right arm (over triceps muscle) using an adjustable strap. The device is very light (83-grams) making this instrument quite non-invasive. The SP2 gathers and combines data from a variety of measurement parameters including 2 accelerometers, heat flux, skin temperature, galvanic skin response, and near body temperature, to objectively estimate EE. Physical characteristics (e.g. height, weight) of the subjects are also taken into considerations by the SP2 (6).

The SP2 is priced similar to other accelerometers, can store up to 11 days of data, and also allows the user to timestamp specific events. The later feature is helpful in the process of data collection. The data collected by the SP2 can be uploaded and analyzed using computer software supplied by the manufacturer (6). The ability to measure heat production and heat loss, in combination with acceleration, may provide advantages over other activity monitors, especially under free-living conditions. The collection of physiological and movement data enables more precise determinations of EE and levels of activity under free-living conditions. Another valuable characteristic of the SP2 is that employs pattern recognition algorithms based on acceleration and other sensor values to detect movement type.

In a recent study (11), Fruin and colleagues assessed the validity of the SP2 EE estimation at rest and with two modes of exercise. In the study, the SP2 was highly reliable at estimating EE at rest and produced similar mean estimates of EE on a cycle ergometer compared to indirect calorimetry. On the other hand, the researchers reported an overestimation of EE (14-38%) during walking on a horizontal surface and an underestimation of EE (22%) of walking on a 5% grade surface. However, the software used in that study was one of the first versions of the Innerview™ Research Software (Version 1.0).

In another study (13), researchers tested the validity of the SP2 to assess EE during treadmill walking, stair stepping, cycle ergometry, and arm ergometry. Open-circuit (indirect) calorimetry was the criterion method used to assess EE. When a generalized algorithm provided by the manufacturer was applied to the data, the results showed an underestimation of EE during walking, cycle ergometer, and stepping exercise, and an overestimation of EE during arm ergometer exercise. After exercise-specific algorithms were applied to the data, the estimates from EE improved considerably, erasing the significant differences in total EE estimates between SP2 and indirect calorimetry for the four exercise modes. The researchers concluded that in order to obtain accurate estimates of EE from the SP2 in comparison with indirect calorimetry, exercise-specific algorithms must be applied. King and colleagues (15) evaluated the validity of the SP2 and 4 accelerometers (CSA, the TriTrac-R3D, the RT3 and the BioTrainer-Pro). EE from various treadmill walking and running speeds were measured by indirect calorimetry and compared to the estimates from the monitors. The results indicated that the SP2 to provide the best estimates of total EE at most speeds, with the exception of slow walking. However, the SP2 overestimated EE during those walking and running speeds, as previously shown in other studies (11, 13) before the application of exercise-specific algorithms to the data. In a study by McClain and colleagues in our laboratory, the SP2 showed moderate to high correlations (range: r=0.77 to r=0.88) when compared to indirect calorimetry during locomotor activities. However, when monitoring activities involving arm movement and locomotor activities on incline planes, the SP2 seemed to overestimate EE (23).

The results from these studies (11, 13, 15, 23) are consistent and showed the potential of the SP2 to accurately assess EE and levels of PA when exercise-specific algorithms are applied. The current version of the Innerview^{TM} Research Software (Version 4.1) includes those exercise-specific algorithms. Furthermore, results from our laboratory support the utility of the new software (37). To date, few studies have evaluated the validity of the SP2 under free-living conditions (37); therefore, future studies assessing the adaptability of the SP2 in free-living settings are needed.

Intelligent Device for Energy Expenditure and Activity (IDEEA)

A new device with potential to solve many problems related to physical activity research has recently been developed. The Intelligent Device for Energy Expenditure and Activity (IDEEA) (MiniSun, Fresno, CA) is an instrument with potential to accurately analyze body motion, measure PA and behavior patterns, and estimate EE in a free-living environment (24).

The IDEEA monitor consists of a light (59-grams) data collection microcomputer with powerful memory and storage capacity and five sets of sensors. The sets of sensors are attached to the chest, thighs and feet, and are able to measure angles of body segments and movement (acceleration) in 2 orthogonal directions. Different signal combinations from those sensors are sent to the microcomputer through thin flexible cables, and complex pattern recognition algorithms are used to determine the predominant movement patterns or type of activity being performed (24). The microcomputer can record up to 7 days of continuous activity. The gathered information can then be downloaded from the monitor into a computer, and properly analyzed using a specially designed software program (ActView™ Software).

Major advantages of the IDEEA device include: detection and recording of body motion and postures changes and identification of more than 40 types of PA. This capability allows the researcher to understand the PA patterns of individual throughout the day. The IDEEA has been shown to provide accurate recordings of onset, duration, frequency, and intensity in a wide variety of physical activities. In a recent validity study (39), the IDEEA monitor accurately identified (mean 98.9%) posture and limb movement type, as well as gait type with high accuracy (mean 98.5%).

The IDEEA also provides both instantaneous and cumulative results of power, amount of mechanical work, and energy expenditure estimates in free-living condition, during a given period (up to multiple days), with considerable accuracy (24). In a study by Zhang and colleagues (38), EE estimations of the IDEEA monitor was shown to highly correlate (r=0.95) with EE measured in a metabolic chamber, during different physical activities. Those results clearly contrast with previous studies in accelerometry-based activity monitors, which have consistently shown limitations in estimating EE (4, 7, 12, 14, 16, 17, 26, 28, 30).

Major limitations of the IDEEA monitor are the high cost of the monitor (~$4,000.-) and its invasiveness. The five sets of sensors placed at the soles of the feet, upper legs and chest, and connected with cables to the microcomputer can become quite uncomfortable after prolonged periods of time. Another shortcoming of the IDEEA is the impossibility to accurately detect PA involving arm movement, a limitation that could be addressed in the future by placing additional sensors in the arms. However, the accuracy of IDEEA to identify and quantify a wide variety of physical activities in free-living environment positions the instrument to be utilized as criterion measure to assess other PA measurements.

Summary

The recent interest of studies involving PA assessment under field conditions is producing considerable advances in instruments designed to assess PA and EE under-free living conditions. However, new challenges have also become evident. The ability to integrate information from multiple sensors and the identification of patterns of movement, common characteristics between the SP2 and the IDEEA monitor, seem to present promising solutions to improve activity assessment.

CHAPTER III- MATERIALS AND METHODS

Participants

The participants in the study were 20 healthy (age range: 22-41 yr) males (n=10) and females (n=10) from a University in the Midwestern region of the United States. Approval from the Institutional Review Board was obtained before the beginning of the study. Procedures and purposes of the study were explained to the all the participants before they signed the informed consent document. All subjects completed medical health forms and a physical activity readiness questionnaire before participating in the study.

PA/EE Measurements

Three instruments were used in the study and each is described separately:

1. The Intelligent Device for Energy Expenditure (IDEEA). The IDEEA monitor (24) consists of a light (59-grams) data collection microcomputer and five sets of sensors. The sets of sensors are attached to the chest, thighs and soles of the feet, and are able to measure angles of body segments and movement (acceleration) in 2 orthogonal directions (appendix). Different signal combinations from those sensors are sent to the microcomputer through thin flexible cables and complex pattern recognition algorithms are used to determine the predominant movement patterns or type of activity being performed. Output measures from the software include energy expenditure (kcal/min), speed and distance, power output, the activity being performed, body position, and gait analysis.

Two previous studies from the same laboratory (38, 39) showed that the IDEEA monitor can accurately measure PA and EE. Furthermore, the IDEEA monitor has also shown to accurately detect (98% accuracy) type, duration and intensity of activities. In a recent study in our laboratory (37) the IDEEA monitor was used as a criterion measure to validate two field-oriented activity monitors. Together, the previous studies support the validity and feasibility of the IDEEA monitor as a criterion measure under free-living conditions. In the present study, the IDEEA monitor was utilized as a criterion measure to evaluate its agreement with the SP2 monitor and the 24PAR.

2. *SenseWear Pro2 Armband (SP2).* The SP2 (14) uses pattern recognition algorithms to determine the principal patterns of movement taking place and applies EE estimates for the characteristics of the activity. The SP2 is a wireless multi-sensor monitor designed to estimate energy expenditure and levels of activity in a variety of settings, especially under free-living conditions. The light device (83-grams) is worn on the back of the upper right arm (over triceps muscle) using an adjustable strap making this instrument non-invasive (appendix). The SP2 collects and combines data from a variety of measurement parameters including 2 accelerometers, heat flux, skin temperature, galvanic skin response, and near body temperature to estimate EE. The SP2 also contains a button that when pressed (time-stamp) allows marking a significant moment during the recording (i.e.: change in posture, change in exercise mode). The data collected by the SP2 can then be uploaded and analyzed using computer software (Innerview™ Research Software 4.1) (6). The ability to collect different physiological and movement data may enable more precise determinations of EE (kcal/min) and levels of PA under free-living conditions. Another valuable characteristic of the SP2 is that it employs pattern recognition algorithms based on acceleration and other sensor values to detect movement type.

In recent studies (11, 15, 23), the SP2 provided reliable and valid estimates of EE. Among other advantages of the SP2 are its capacity to detect upper-body movement since it is worn over the triceps muscle, its noninvasiveness and its financial cost. However, to date, few studies have assessed the SP2 accuracy under free-living conditions.

3. *24-hour Physical Activity Recall (24PAR).* The 24PAR is a semi-structured, interviewer-administered PA assessment that estimates the average EE for the previous day. The interviewer leads the participant systematically back through the previous 24 hours gathering information about occupational, household and leisure-time activities and, using this information an estimate of the daily energy expenditure in kcal/day is derived. The 24PAR also has been used to quantify the amount of time spent in major PA in the previous day.

In a previous study of 53 adults (53% women, 43.0±16.5 yr), the 24PAR showed significant correlations for sitting time ($r = 0.67$), household ($r = 0.53$), occupational ($r = 0.56$), leisure ($r = 0.74$) and total activity ($r = 0.31$), when compared to another PA questionnaire (Physical Activity Log (PAL)). The 24PAR was also compared to an activity monitor (CSA) and significant correlations for household ($r=0.29$), leisure time ($r=0.54$), sitting time compared to inactivity ($r=0.47$) and total activities ($r=0.31$) were noted. However, no significant correlations were found for occupational activity (21).

In the present study, a computerized version of the 24PAR protocol was utilized (C. Matthews, Vanderbilt University - personal communication). The program uses an integrated ACCESS database to store and process the data and an associated SAS program to code the activities using the established MET values from the Compendium of Physical Activity (2, 3). The use of this tool improved the accuracy of scoring the 24PAR since the coding algorithms were already built into the software.

Procedures

Participants reported to the laboratory in the morning between 7 and 9 a.m. of their scheduled day of testing (all of the trials were recorded during week days). Anthropometric measures were taken to the participants. Standing height was measured to the nearest 0.1 cm with the use of a wall mounted Harpenden stadiometer (Harpenden, London, UK) and with the participants barefooted. Body mass was measured with participants in light clothes and barefooted on an electronic scale (Seca 770) to the nearest 0.1 kg. The body mass index (BMI) was calculated as weight (kg)/height^2 (m^2). IDEEA and SP2 monitors were fitted and initialized according to manufacturer's recommendations. The IDEEA monitor was set to record 1-second intervals while the SP2 only allows recording 1-minute intervals when recording for more than 1 hour periods.

Participants were asked to wear the monitors during the rest of their active day in which they performed their normal activities, excluding swimming and showering. Participants were asked to incorporate at least 30-60 minutes of MVPA during the day to increase the variability of activities recorded. Participants in the study were randomly assigned to maintain a detailed diary of the activities performed during one of the two days of monitoring (Table 2). The subsequent morning, following the completion of their monitoring period, participants reported back to the laboratory to return the monitors and complete a structured 24PAR interview administered by a trained researcher (MAC), following guidelines of the 24PAR System. After data collection, the IDEEA and SP2 monitors were downloaded using manufacturer's recommended procedures (6, 24). Data was saved in individual files and later merged into a final data set synchronizing time periods matching the two monitors.

During a pilot study, we observed an inconsistent delay in the initialization of the data collection from the IDEEA monitor making it difficult to match the output data of this device with data from the SP2 monitor. Therefore, in order to synchronize the start of the monitors the participants changed posture at the same time they time-stamped the SP2 monitor. Later, the changes in posture of the IDEEA output were matched with the time-stamp mark from the SP2 to complete the data synchronization. All computer-based initialization procedures were preformed on the same machine.

In order to account for variability between monitors, only 2 IDEEA and 2 SP2 monitors were used during the study. The monitors were randomly assigned to the participants during their first trial and each participant used the same IDEEA and SP2 monitor during their second trial. During the study, 4 out of the 40 trials had to be repeated due to recording problems with the IDEEA monitor.

Data Processing and Analysis

Primary Objective- *Measurement Agreement between Monitors*: Agreement in activity measures was examined on an individual and group basis using the temporally matched data from the IDEEA and the SP2. Correlations between the minute-by-minute values from the two devices were computed for each individual and the mean correlation across the participants reflects the overall agreement between the devices. Group level estimates of EE (kcal/day) and time spent in MVPA (min/day) for the 3 instruments (IDEEA, SP2 and 24PAR) were also compared using t-tests and Bland Altman graphical procedures. Estimates of EE were based on internal algorithms in each device. The time spent in MVPA was determined for each participant by adding the time the participants spent in activities requiring more than 3 METS, generally considered the threshold for moderate PA (27).

Secondary Objective- *Recall Accuracy.* The accuracy in recalling activities was determined with correlation analyses, statistical tests of mean differences in EE estimates and with Bland Altman graphical procedures. Comparisons using t-tests were also made between the trial in which participants were assigned to keep the activity diary and the non-diary trial to determine if the logging improved the accuracy of the interview estimate. Only active time minutes were used from the 24PAR instrument. We considered active time as only the time period where participants recalled wearing both activity monitors.

In order to examine individual agreement across the range of activity levels Bland Altman plots (5) were utilized. Confidence intervals defining the limits of agreement were established as 2 SD from the mean difference. Statistical analyses were conducted using SAS version 9.0.

CHAPTER IV- RESULTS

Descriptive statistics were computed for the sample and are included in Table 1. Participant's ages ranged from 22 to 41 years. Body mass index (BMI) values ranged from 20.0 to 33.0 Kg/m² in males and from 18.0 to 32.0 Kg/m² in females. Self-reported fitness ratings (based in a 1-10 scale and necessary for the IDEEA monitor's programming) ranged from 5 to 8 for males and from 5 to 9 in females.

Participants wore the IDEEA and SP2 monitors during their normal active days. The average time recorded with participants wearing both monitors was 809± 125 minutes. The average active time reported by participants during their interviews was 823± 129 minutes, ranging from 370 and 1010 minutes.

Estimates of Energy Expenditure and Physical Activity

Table 3 provides descriptive statistics for mean total (daily) EE estimates and MVPA. On average, the SP2 underestimated IDEEA total EE by 62.1 kcal/day. The differences in total EE estimates between the IDEEA and the SP2 ranged between 787.7 to -952.1 kcal/day. On average, the 24PAR instrument overestimated IDEEA total EE by 102.0 kcal/day. The differences in estimates between the IDEEA and the 24PAR for total EE ranged from 565.9 to -782.2 kcal/day. Statistically significant differences in EE estimates were found between the IDEEA and SP2 monitors when compared to the 24PAR instrument, but not between the two monitors (IDEEA and SP2). However, the effect sizes (ES) for the three comparisons were low (IDEEA-24PAR=-0.185, SP2-24PAR=-0.304, IDEEA-SP2= 0.111), diminishing the meaningfulness of these differences. Comparisons between the diary trial and the non-diary trial for absolute EE did not differ (P=0.18), hence, the use of the diary did not improve recall accuracy for estimates of total EE. In Figure 1, Bland Altman plots show the distribution of error for total EE estimation. No systematic form of bias can be observed in the plot's patterns.

While the EE estimates were fairly consistent there was more variability in the PA estimates (Coefficient of Variation (CV)-IDEEA= 52%, CV-SP2=44%, CV-24PAR=66%). On average, the 24PAR had the smallest amount of minutes of MVPA for both trials (mean=111.5±73.2), and the SP2 had the highest values also for both trials (mean= 170.3±74.8). The estimated amount of MVPA that the participants engaged in during the trials exhibited similar ranges (PAR: 5-315 minutes, IDEEA: 23-307 minutes, SP2: 35-315 minutes). Individual estimates were generally consistent; however, there were some exceptions. According to the IDEEA monitor's estimates, one participant failed to accomplish the goal of engaging in more than 30 minutes of MVPA (the participant's value was 23 minutes). However, for the same trial (and participant), the SP2 estimated a value of 123 minutes and the 24PAR an estimate of 80 minutes. Bland Altman plots show the overall distribution of error for estimation of minutes of MVPA (Figure 2). The plot patterns do not show any systematic form of bias.

Correlations among Measures

Pearson correlation coefficients for total EE estimates are provided in Table 4. The mean total estimated EE correlation was used to reflect the overall agreement between the measures. The correlations for the three instruments ranged between r=.80 to r=0.91.

Pearson correlation coefficients for estimated minutes of MVPA are shown in Table 5. The SP2 monitor was moderately correlated with both the IDEEA monitor (r=0.47) and the 24PAR (r=0.59) for MVPA. On the other hand, the IDEEA and the 24PAR had a low correlation (r=0.14) for minutes of MVPA. When comparing MVPA, the 24PAR diary trial did show more accurate values than the non-diary trial when correlated to values from the IDEEA and the SP2 monitors. When correlating total minutes of MVPA, the diary trial correlated higher with the SP2 monitor (r=0.72, P<0.0003), than the correlation values showed between the IDEEA and the SP2 monitors (Table 5).

Pair wise individual correlations for estimated EE between the IDEEA and the SP2 monitors were computed using minute-by-minute data to examine agreement in more detail. These correlations are shown in Table 6 along with the total time recorded for each participant and the difference in total EE estimates between the two monitors. The individual correlation values ranged from r= 0.45 to r= 0.96, with a mean value of r=0.76. The distribution of the coefficients followed a normal distribution with some degree of negative skewness (Figure 4). Twenty-eight of the 40 trials (70%) had correlation coefficients higher than 0.70, suggesting high min-min agreement between the IDEEA and the SP2 for estimated EE. Those 12 trials were recorded by 8 participants, with 4 of those participants having both trials showing correlation values lower than 0.70. Interestingly, the remaining 4 participants that had one low correlation trial had also a second trial correlation lower or very close to the mean value (r=0.76). Therefore, a trend of lower agreement for some of the participant's was evident.

Sitting time comparison between the IDEEA and the 24HR Physical Activity Recall (24PAR)

Sitting time recorded by the IDEEA monitor and the reported sitting time of the participants to the 24PAR instrument highly correlated (r=0.815, P<0.0001). Total sitting time from the IDEEA monitor was calculated adding sitting activities, sitting transitions, laying activities and laying transitions. Table 7 includes descriptive statistics of total sitting time percentage and MVPA percentage for the IDEEA monitor and the 24PAR instrument.

Figure 3 shows a Bland Altman plot of sitting time percentage comparison between the IDEEA monitor and the 24PAR instrument. In the figure, a systematic error bias is noticeable. As sitting time percentage increases the 24PAR instrument seems to overestimate sitting time compared to the IDEEA monitor.

CHAPTER V- DISCUSSION

This study examined the agreement between the IDEEA, the SP2 monitor and the 24PAR recall instrument during an active day. The primary purpose of the study was to compare the SP2 to the IDEEA under free-living conditions. The IDEEA was used as a criterion measure, and even though it cannot be considered a perfect standard, it can be used as a valid criterion measure to assess EE and PA in free-living environments. The SP2 showed small group differences in EE estimates and high correlations with the IDEEA monitor. These results support previous findings from our laboratory (37) that the SP2 may provide a similar estimate of PA and EE. In the present study the participants wore the monitors for prolonged periods of time and engaged in at least 30 minutes of MVPA. Both of these design aspects give the findings stronger support.

In the minute-by-minute correlations comparing the EE outputs of the two monitors, those participants with lower correlations did not differ from the high correlation participants in gender, monitor used or BMI. After plotting each participant's activity patterns using the output from the IDEEA monitor for 10 different activity categories (Appendix), no apparent difference in the activity patterns was evident between the high and low correlation groups. However, some of the participant's showing lower correlations engaged in activities such as tennis, cycling, and driving for more than 1 hour, activities not observed in the high correlation group. Furthermore, in the only trial where a participant reported playing tennis for more than 1 hour, the SP2 overestimated total EE by 952.1 Kcal/day (highest difference between monitors). Therefore, the type of activities participants performed while wearing the two monitors may explain the low values showed by some participants. Previous studies have mentioned the inability of the IDEEA monitor to identify upper extremities movements (38, 39), and to date no study has reported the validity of the IDEEA to detect cycling patterns.

On the other hand, the SP2 might experience difficulties to detect fidgeting or similar light lower body movements, components of nonexercise activity thermogenesis (NEAT) (18), due to it's positioning on the right arm. Furthermore, overestimation of EE during arm movements and activities involving inclined planes was previously reported in a study assessing the validity of the SP2 (23). Therefore, the limitations of each of the devices might decrease their mutual agreement during certain type of activities. Future research should focus on assessing the specific limitations of each of the devices during specific activities (e.g. tennis, cycling, weight lifting and driving).

The limitations of both monitors may also explain the moderate correlation between the IDEEA and the SP2 in MVPA. At the same time, the ability of the SP2 to agree with the other two instruments might provide evidence about the capability of the SP2 to accurately detect physical activities of more diverse characteristics than the other two instruments.

The secondary purpose of the study was to evaluate the ability of participants to recall information about the physical activity they performed using the IDEEA and SP2 as criterion measures. To our knowledge this is the first study that compares a self-report instrument (24PAR) to the IDEEA and the SP2 monitors, to quantify PA and EE. The 24PAR showed very small absolute EE estimate differences and was highly correlated with the IDEEA and the SP2 monitors. When comparing to absolute sitting time, the 24PAR and the IDEEA monitor also showed high agreement. However, Bland Altman plots for sitting time showed systematic error for the 24PAR instrument, which seems to slightly overestimate sitting time compared to the IDEEA monitor as sitting time increases.

We observed stronger validity coefficients than previously reported by Matthews and colleagues (20, 21) for comparisons between the 24PAR instrument and accelerometers

(CSA, Actillume). In those previous studies, low to moderate correlations were reported for both total activity (r=0.31) and sitting time (r=0.47) (21). In this study, the advantages of using a better criterion measure as an improvement in studying the validity of self-report instruments are therefore highlighted. These findings might be of great value considering the feasibility of self-report instruments compared to the cost-effectiveness of the IDEEA monitor, and knowing that self-report instruments are currently the most commonly used method of assessing PA in epidemiologic studies (19).

During PA, recall agreement between the 24PAR and the IDEEA monitor was low and not significant. Total amount of minutes of MVPA recorded by the 24PAR were lower for both trials (diary and non-diary) compared to the estimates from the IDEEA monitor and the SP2 monitor (highest values for both trials). Therefore, the 24PAR instrument underestimated MVPA. Altogether, these findings may show that the biggest sources of error between 24PAR and the IDEEA and SP2 monitors were found during MVPA. These findings might support previous questions about the ability of self-report instruments to accurately quantify PA, especially of moderate intensities (32).

In this study, the results of the use of a diary were equivocal. Diary use did not seemed to help improve recall accuracy for total EE and total sitting time compared to the non-diary trial. However, when evaluating the accuracy of the participants to recall minutes of MVPA, the diary trial showed higher correlation values than the non-diary trial.

Among the limitations of the study are the narrow characteristics of the sample. Most participants were college educated, physically active and with narrow age range (22-41 yr). Therefore our results may be less generalizable for populations with more diverse characteristics. Future studies should focus in the ability of the IDEEA, SP2 and 24PAR to assess different populations, different occupations and different levels of PA.

In summary, the SP2 monitor was found to be a valid instrument to measure total EE and PA under free-living conditions. The 24PAR showed to be a valid tool to measure total activity and sitting time; however, it was not as valid when measuring PA. The differences in correlation values between EE and MVPA might be explained by the fact that EE estimates take into consideration body mass. In this study, the use of a dairy to improve recalls accuracy proved to be helpful only when recalling minutes of MVPA. The findings of this study will be of great value for projects involving population surveillance, factors that influence PA behavior and assessment of interventions promoting physical activity.

CHAPTER VI- REFERENCES

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CHAPTER VII- TABLES AND FIGURES

Table 1. Sample population characteristics.
Values represent means ±SD.

	n	Age (yrs)	Height (cm)	Weight (Kg)	BMI (Kg/m^2)	Self-Report Fitness Rating (1-10)
Males	10	31.6± 6.3	180.5± 8.5	82.8± 11.1	25.5± 4.1	6.9± 1.0
Females	10	28.1± 4.6	162.4± 5.2	61.0± 11.1	23.1± 4.1	7.3± 1.2
All	20	29.9± 5.7	171.4± 11.5	71.9± 15.6	24.4± 4.1	7.1± 1.1

Table 2- Random Trial Assignment.

Participants	n	First Trial	Second Trial
Males	5	Non diary	Diary
	5	Diary	Non diary
Females	5	Non diary	Diary
	5	Diary	Non diary

Table 3. Descriptive statistics for energy expenditure and physical activity. Values represent means ± SD.

	Trial	n	IDEEA	SP2	24PAR
Total Estimated EE (kcal/day)	Diary	20	1993± 508 [a]	2014± 544	2136± 647
	Non diary	20	1987± 614	1843± 533 [b c]	2048± 665
	All	40	1990± 557 [a]	1928± 539 [b]	2092± 650
Total MVPA (minutes)	Diary	20	142.8± 73.5	173.9± 73.9 [b]	123.9± 82.1
	Non diary	20	157.0± 84.5 [a]	166.8± 77.3 [b]	100.7± 63.9
	All	40	149.9± 78.5 [a]	170.3± 74.8 [b]	111.5± 73.2

[a] Significant compared to the 24PAR ($P<0.05$)
[b] Significant compared to the 24PAR ($P<0.01$)
[c] Significant compared to the IDEEA ($P<0.05$)
No significant difference between diary and non-diary trial for differences in estimates of total EE.

Table 4. Correlation of total energy expenditure (kcal/day) among IDEEA, SP2 and 24PAR.

a) Diary (n=20)

	SP2	**24PAR**
IDEEA	0.805	0.905
SP2	-	0.912
24PAR	-	-

* All correlations significant at p<0.0001

b) Non Diary (n=20)

	SP2	**24PAR**
IDEEA	0.885	0.906
SP2	-	0.866
24PAR	-	-

* All correlations significant at p<0.0001

c) Average (n=40)

	SP2	**24PAR**
IDEEA	0.834	0.902
SP2	-	0.882
24PAR	-	-

* All correlations significant at p<0.0001

Table 5. Correlation of minutes of moderate-vigorous physical activity among IDEEA, SP2 and 24PAR (Above 3 METS).

a) Diary (n=20)

	SP2	24PAR
IDEEA	0.596*	0.263
SP2	-	0.724**
24PAR	-	-

* Significant at p=0.0056
** Significant at p<0.0003

b) Non Diary (n=20)

	SP2	24PAR
IDEEA	0.383	0.048
SP2	-	0.441
24PAR	-	-

c) Average (n=40)

	SP2	24PAR
IDEEA	0.472*	0.141
SP2	-	0.590**
24PAR	-	-

* Significant at p=0.0021
** Significant at p<0.0001

Table 6. Descriptive statistics using individual data.

	ID	Minutes	IDEEA-SP2	Diff. EE between IDEEA-SP2
Dairy	1	703	0.856	69.2
	2	761	0.579	-952.1
	3	680	0.884	-134.9
	4	924	0.701	-205.7
	5	927	0.894	189.0
	6	867	0.628	-78.2
	7	778	0.956	259.5
	8	806	0.734	-454.8
	9	807	0.614	158.4
	10	790	0.767	498.1
	11	842	0.576	-448.4
	12	904	0.714	-6.0
	13	725	0.806	3.5
	14	708	0.672	-129.1
	15	798	0.664	499.7
	16	883	0.890	-24.0
	17	536	0.930	97.6
	18	907	0.883	178.7
	19	845	0.690	63.3
	20	947	0.695	5.1
Mean ± SD		807±102	0.757±0.121	-20.6±329.8
Non diary	1	985	0.856	230.9
	2	853	0.513	-251.0
	3	645	0.842	313.7
	4	1006	0.945	352.2
	5	929	0.867	223.3
	6	840	0.471	-343.8
	7	766	0.822	140.0
	8	810	0.914	40.7
	9	758	**0.791**	204.6
	10	765	0.835	787.7
	11	890	**0.701**	-255.2
	12	645	0.903	238.2
	13	767	0.851	35.9
	14	778	**0.729**	-239.2
	15	982	**0.710**	572.1
	16	888	0.805	254.5
	17	364	0.780	60.8
	18	940	0.887	158.9
	19	764	0.450	425.5
	20	864	0.531	-53.7
Mean ± SD		812± 147	0.76± 0.153	144.8±286.2

All correlations significant at p<.0001

IDEEA-SP2= Individual correlation of EE estimates using minute-by-minute data from IDEEA and SP2.

Diff. IDEEA-SP2= Individual differences of total EE estimates from IDEEA minus SP2.

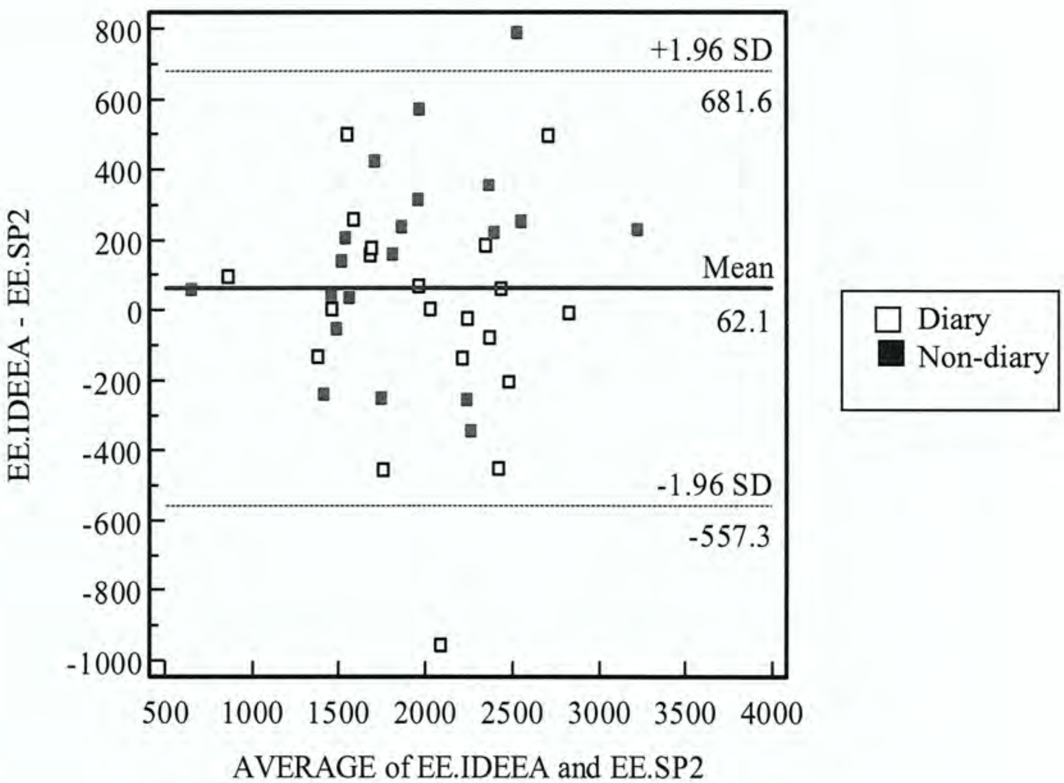
Table 7. Mean percentage of activities

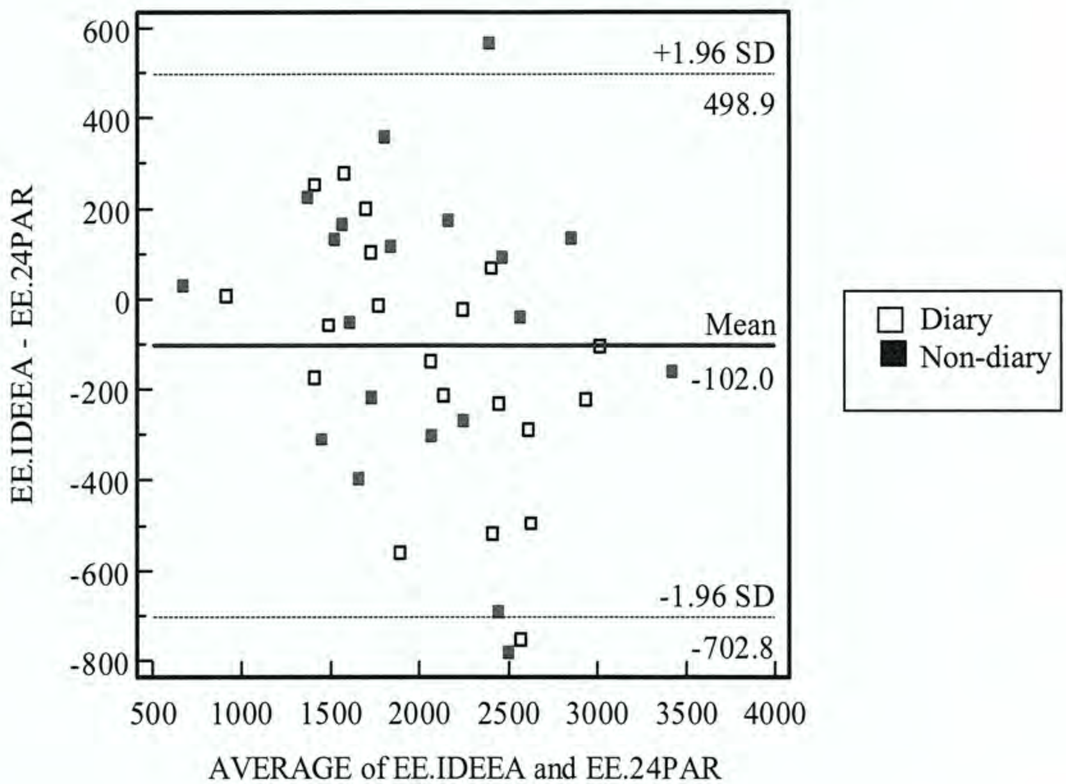
	Total time (min)	Sitting (%)	MVPA (%)
24PAR- All	823±128.9	65.3±13.7	13.5±8.3
Diary	822±107.1	66.2±13.6	14.8±9.3
Non Diary	823±150.5	64.3±14.1	12.1±7.1
IDEEA- All	857±120.3	65.7±10.0	17.3±9.2
Diary	807±102	65.8±9.8	16.7±8.6
Non Diary	812± 147	65.7±10.2	18.1±9.9

(Values are means ± SD)

Figure 1- Bland Altman Plots for total energy expenditure estimates.

Panel A: IDEEA-SP2
Panel B: IDEEA-24PAR
Panel C: SP2-24PAR




600
400
200
0
-200
-400
-600
-800
+1.96 SD
498.9
Mean
-102.0
-1.96 SD
-702.8
EE.IDEEA - EE.24PAR
500 1000 1500 2000 2500 3000 3500 4000
AVERAGE of EE.IDEEA and EE.24PAR
Diary
Non-diary

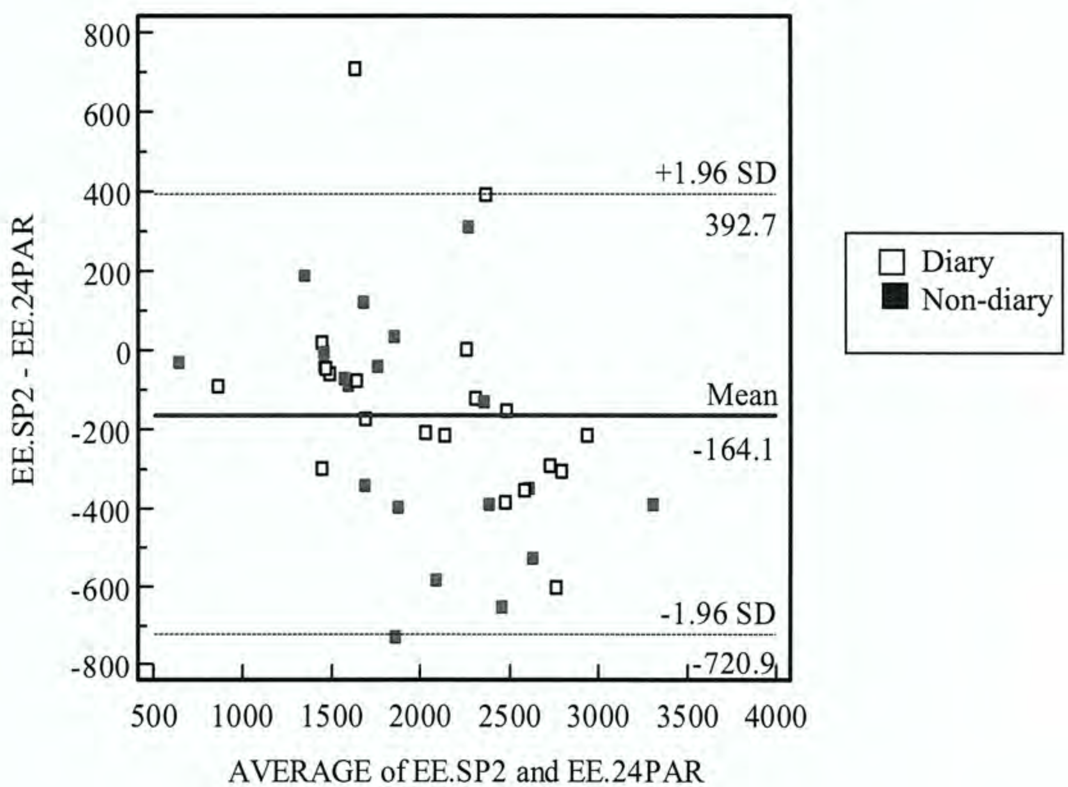
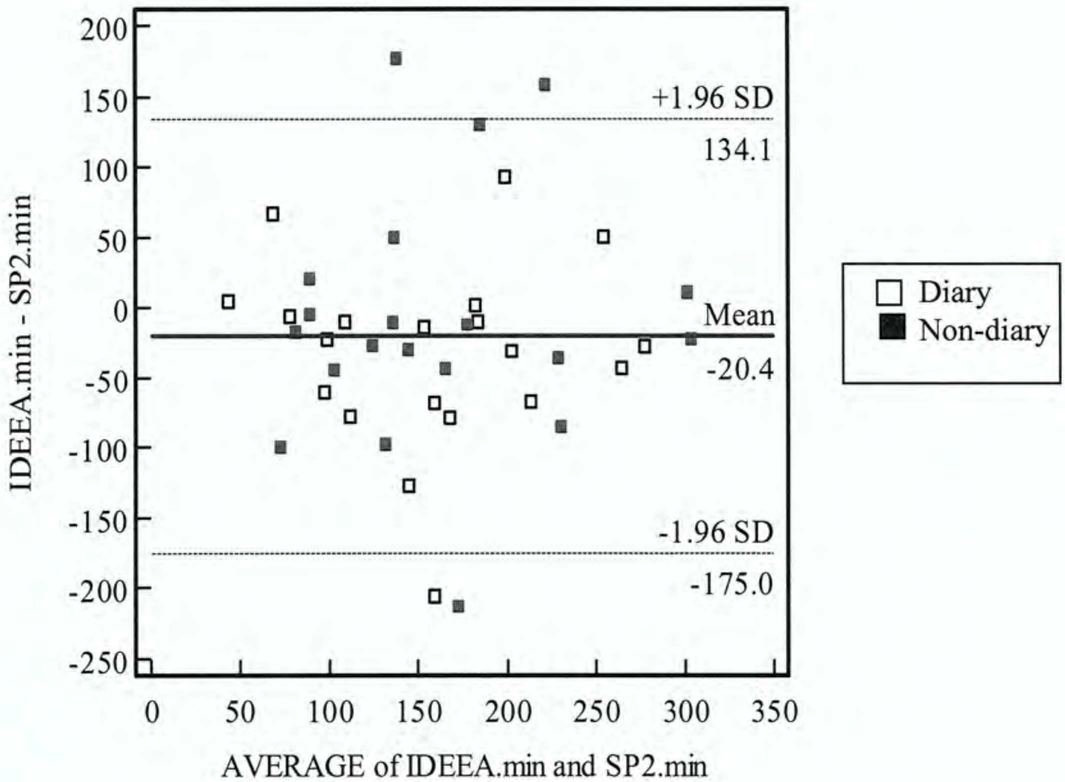
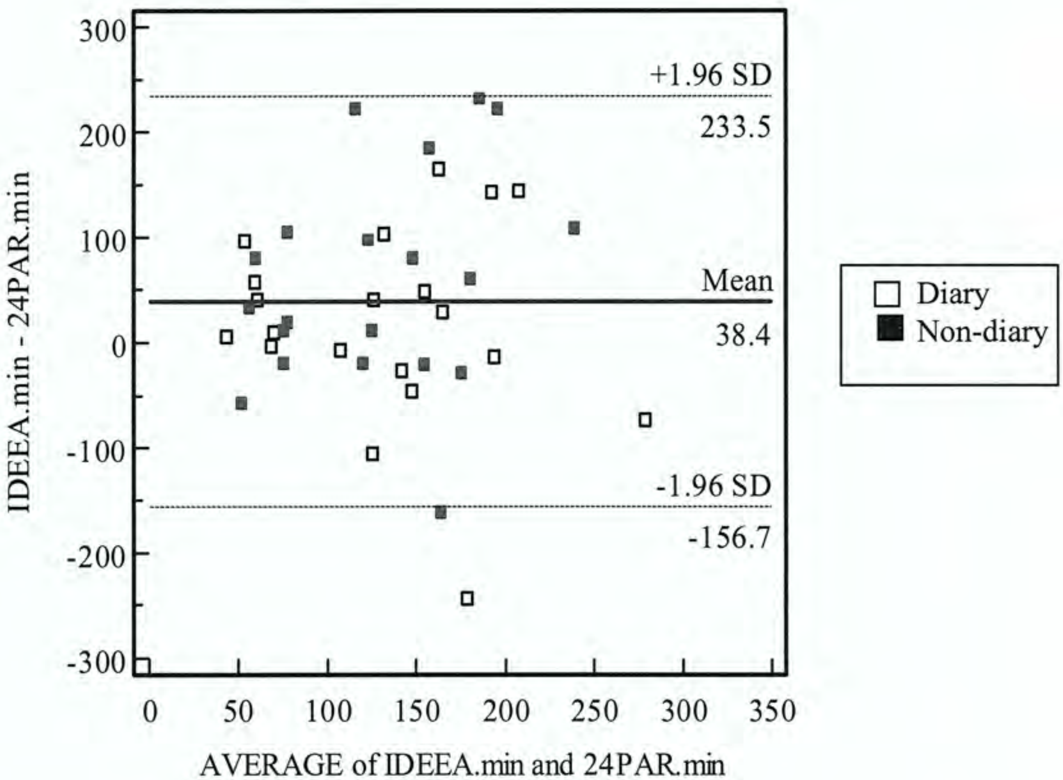

800
600
400
200
0
-200
-400
-600
-800
+1.96 SD
392.7
Mean
-164.1
-1.96 SD
-720.9
EE.SP2 - EE.24PAR
500 1000 1500 2000 2500 3000 3500 4000
AVERAGE of EE.SP2 and EE.24PAR
Diary
Non-diary

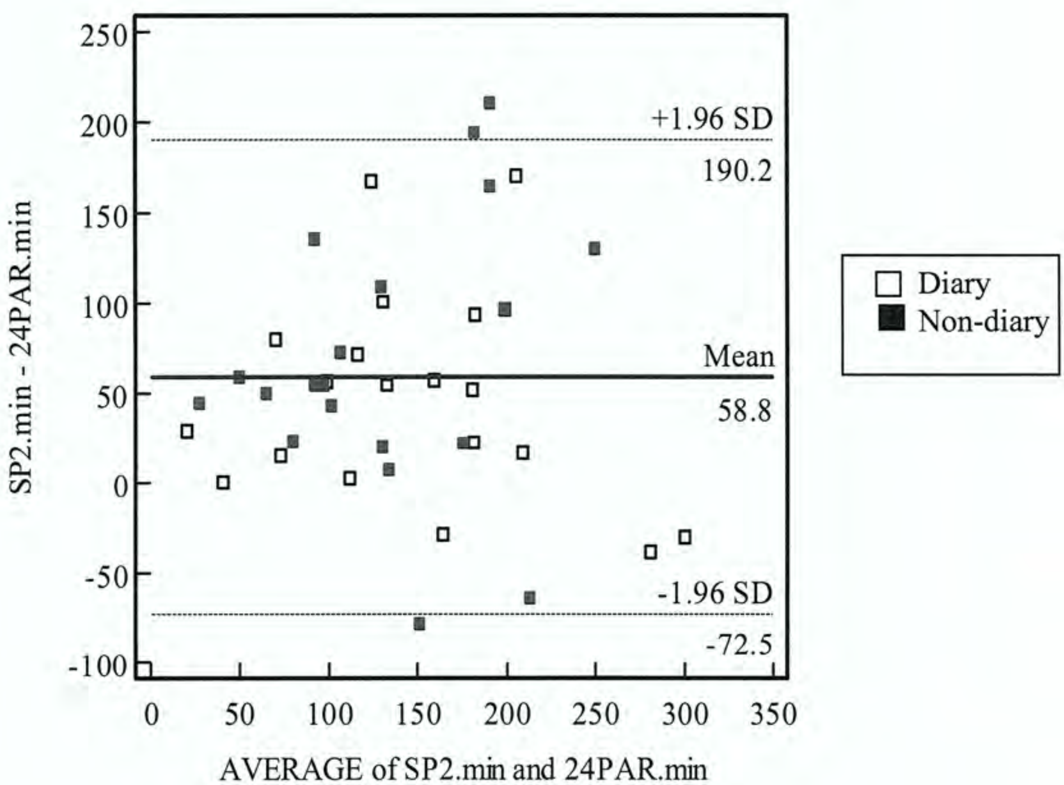
Figure 2- Bland Altman Plots for minutes of MVPA.

Panel A: IDEEA-SP2
Panel B: IDEEA-24PAR
Panel C: SP2-24PAR





300
200
100
0
-100
-200
-300
+1.96 SD
233.5
Mean
38.4
-1.96 SD
-156.7
0
50
100
150
200
250
300
350
IDEEA.min - 24PAR.min
AVERAGE of IDEEA.min and 24PAR.min
Diary
Non-diary



250
200
150
100
50
0
-50
-100
+1.96 SD
190.2
Mean
58.8
-1.96 SD
-72.5
0
50
100
150
200
250
300
350
SP2.min - 24PAR.min
AVERAGE of SP2.min and 24PAR.min
Diary
Non-diary

Figure 3- Bland Altman Plots for Sitting time Percentage- (IDEEA -24PAR)

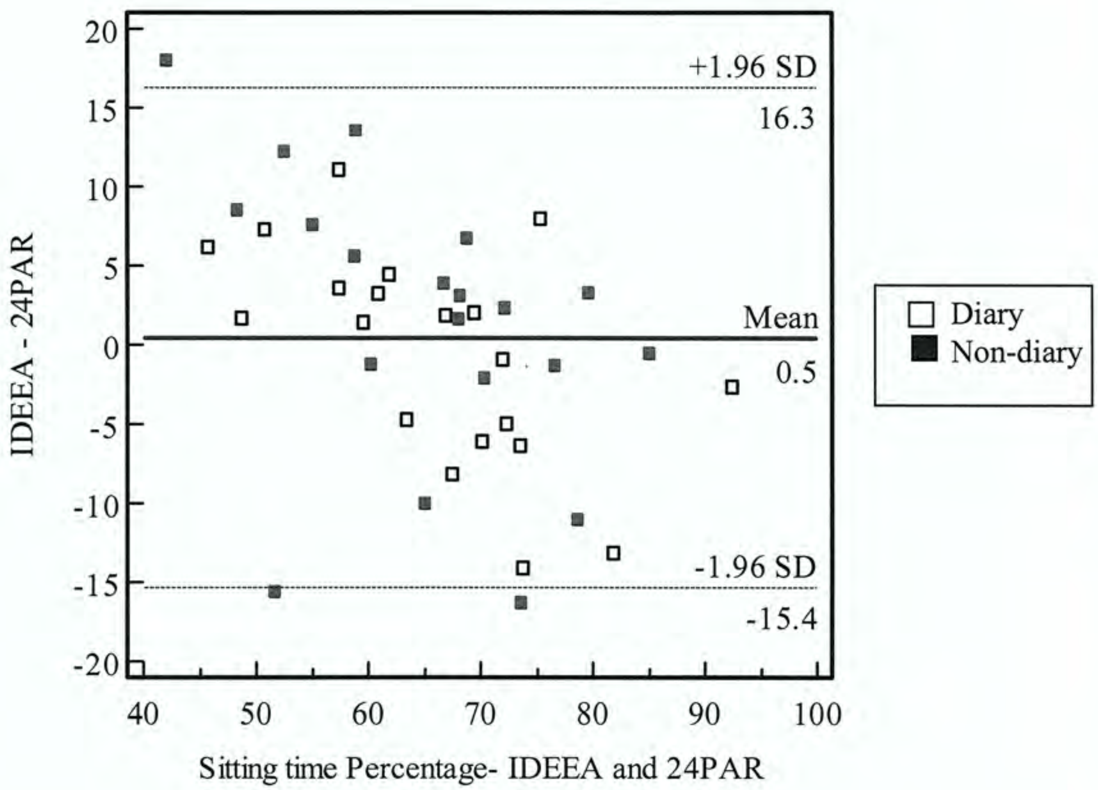
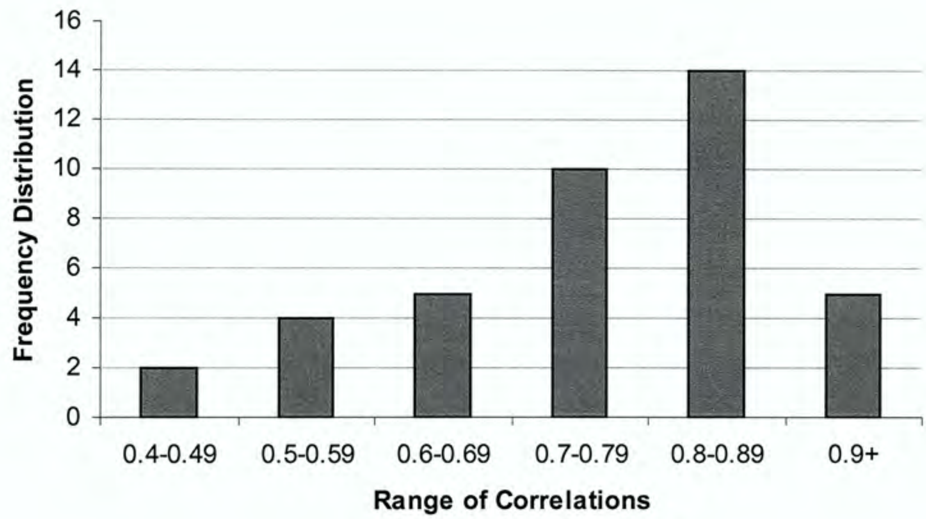
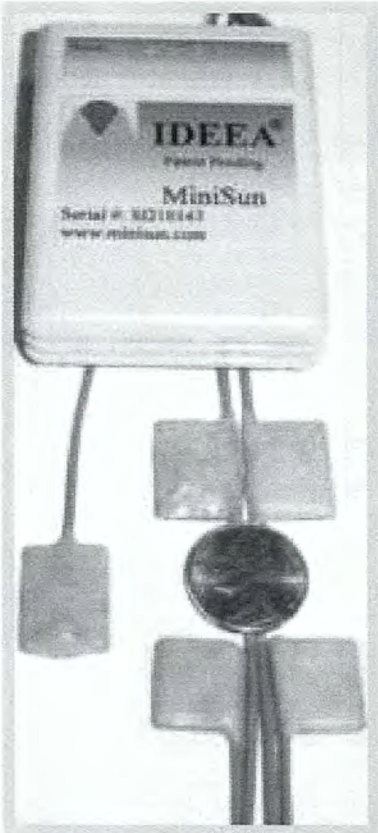


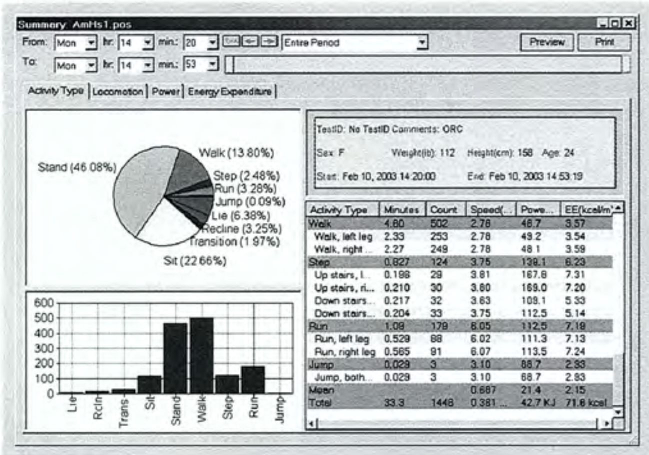
Figure 4- Frequency distribution of correlation coefficients from min-min individual correlations.

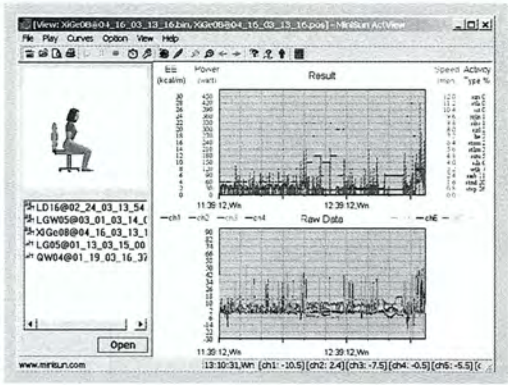


CHAPTER VIII- APPENDIX

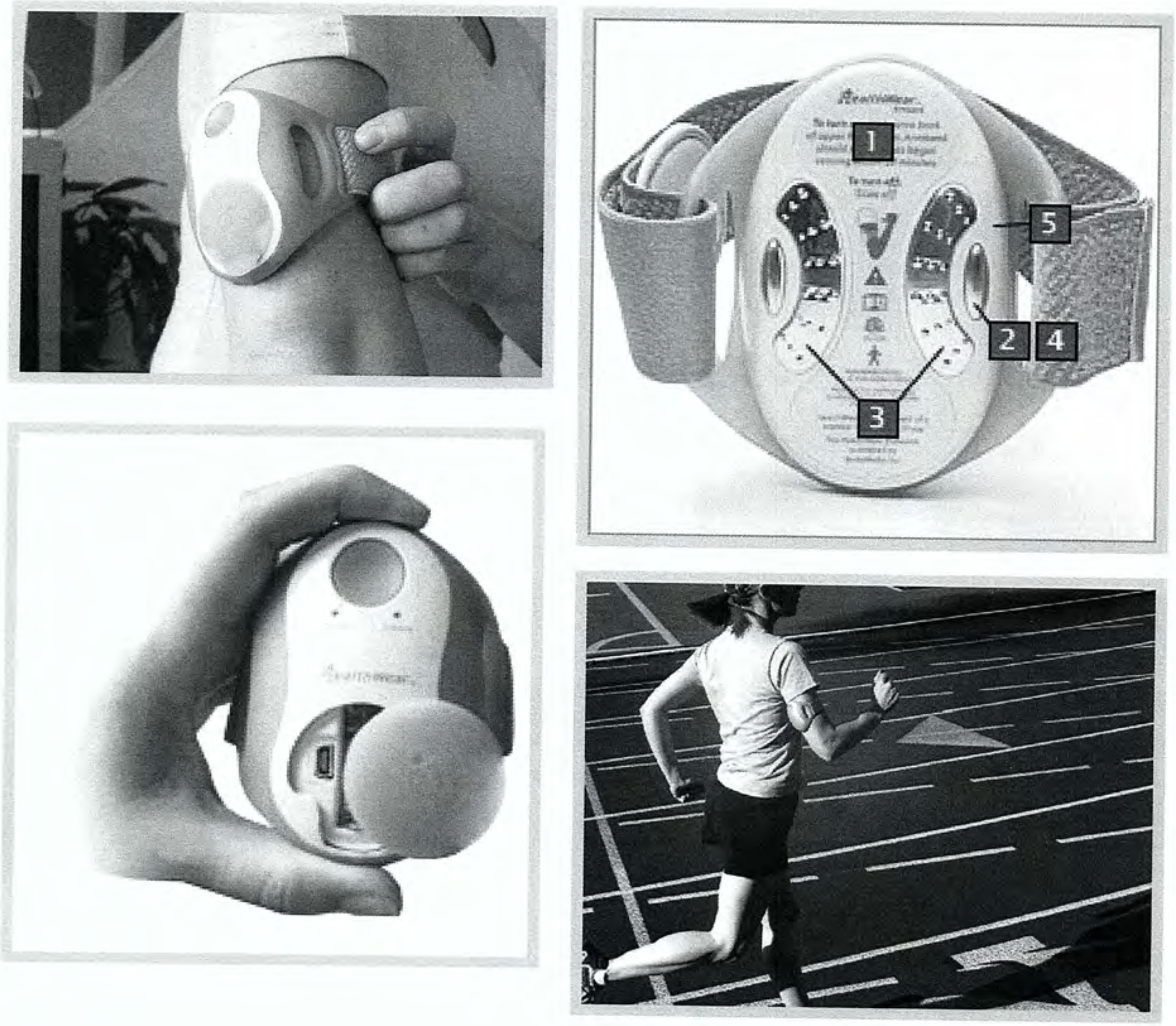
Intelligent Device for Energy Expenditure and Activity (IDEEA)



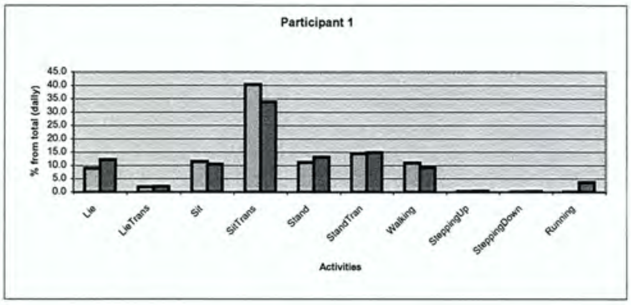


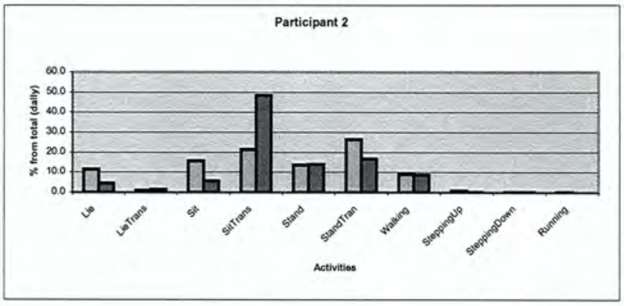


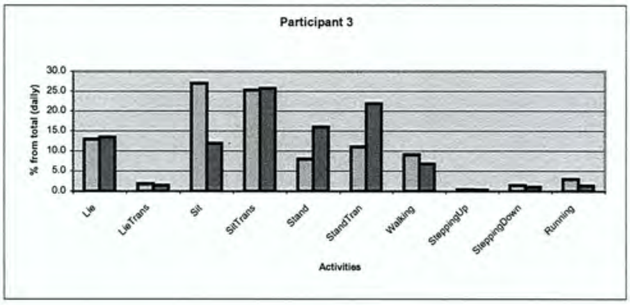
Armband SenseWear Pro 2 (SP2)

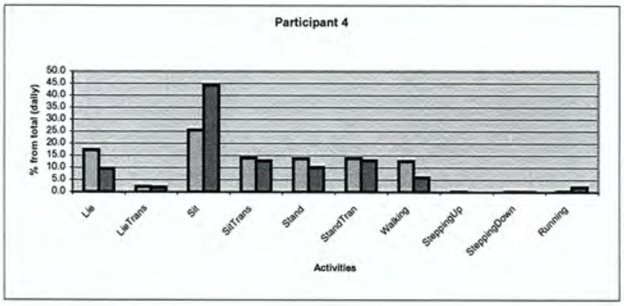


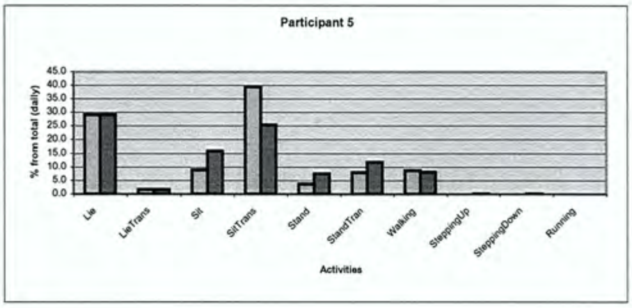
Participant's activity patterns using the output from the IDEEA monitor for 10 different activity categories. (Next page)

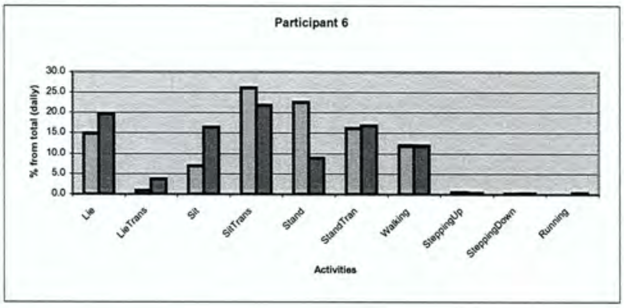

Participant 1
% from total (daily)
Lie
LieTrans
Sit
SitTrans
Stand
StandTran
Walking
SteppingUp
SteppingDown
Running
Activities

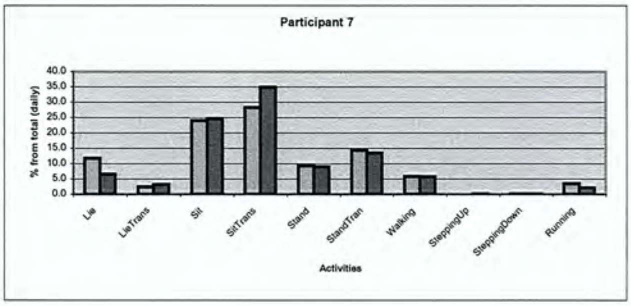

Participant 2
% from total (daily)
Activities

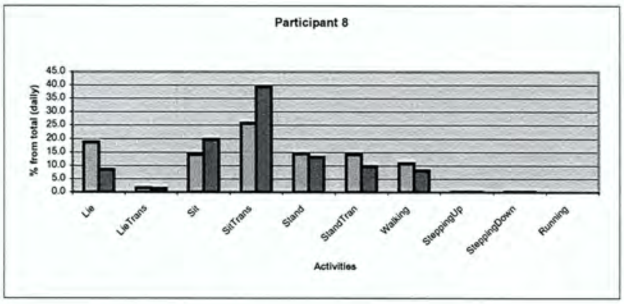

Participant 3
% from total (daily)
Activities

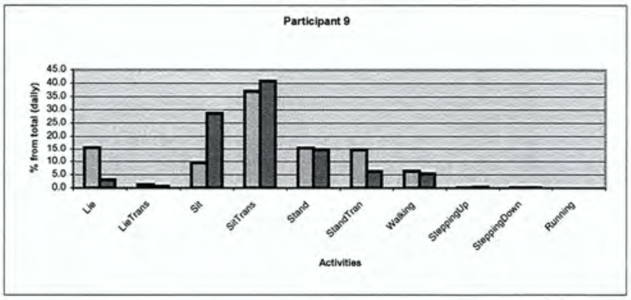

Participant 4
% from total (daily)
Activities

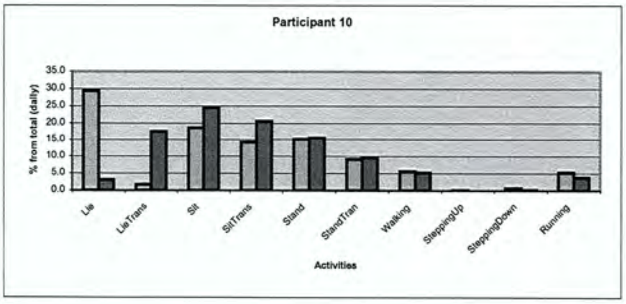

Participant 5
% from total (daily)
Activities

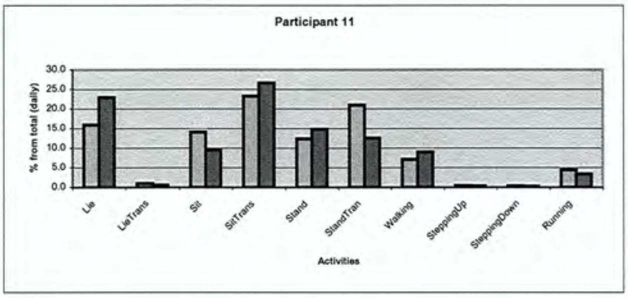

Participant 6
% from total (daily)
Activities

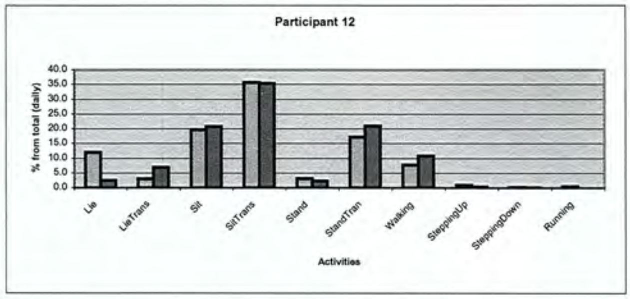

Participant 7
% from total (daily)
Activities

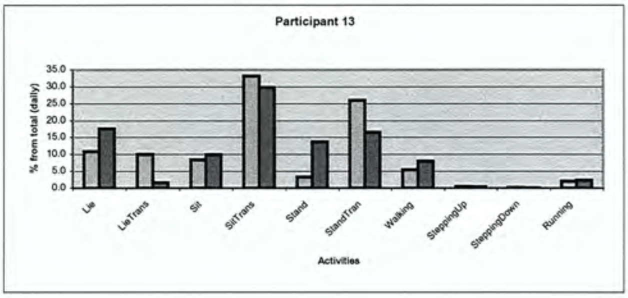

Participant 8
% from total (daily)
Activities

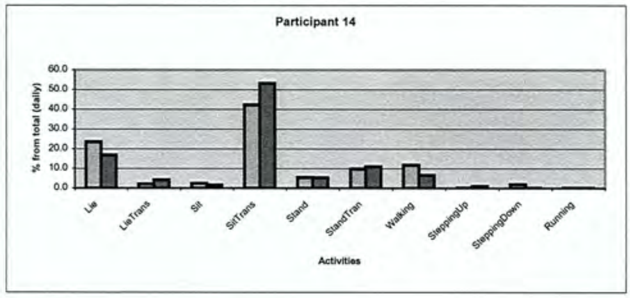

Participant 9
% from total (daily)
Activities

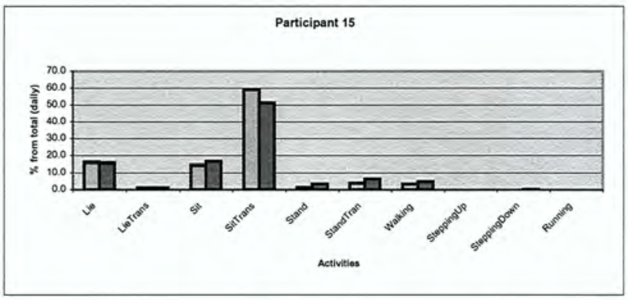

Participant 10
% from total (daily)
Activities

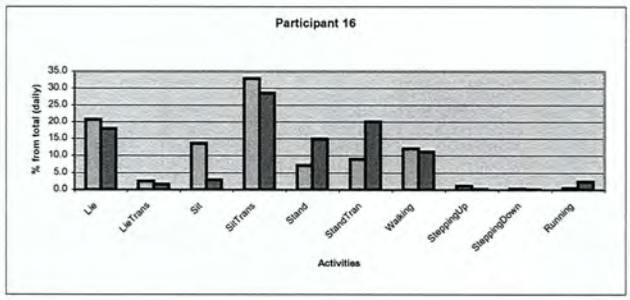

Participant 11
% from total (daily)
Lie
LieTrans
Sit
SitTrans
Stand
StandTran
Walking
SteppingUp
SteppingDown
Running
Activities

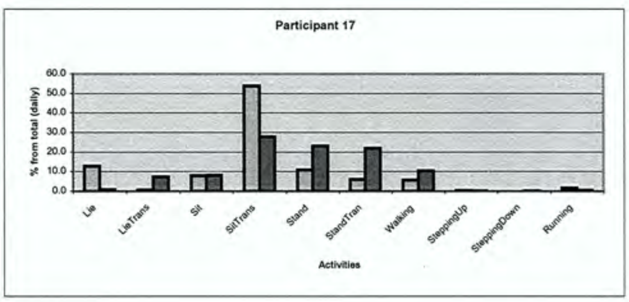

Participant 12
% from total (daily)
Lie
LieTrans
Sit
SitTrans
Stand
StandTran
Walking
SteppingUp
SteppingDown
Running
Activities

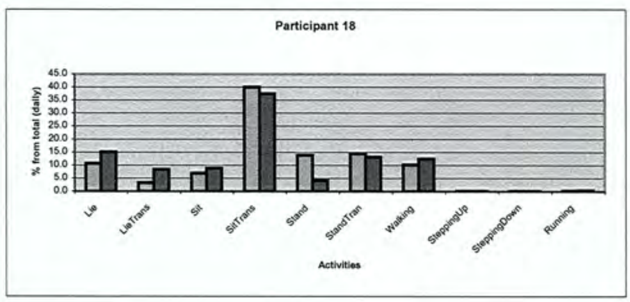

Participant 13
% from total (daily)
Lie
LieTrans
Sit
SitTrans
Stand
StandTran
Walking
SteppingUp
SteppingDown
Running
Activities

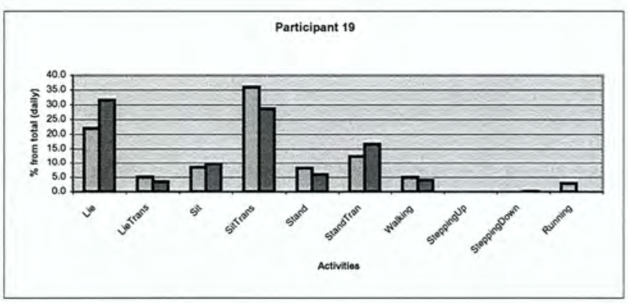

Participant 14
% from total (daily)
Lie
LieTrans
Sit
SitTrans
Stand
StandTran
Walking
SteppingUp
SteppingDown
Running
Activities

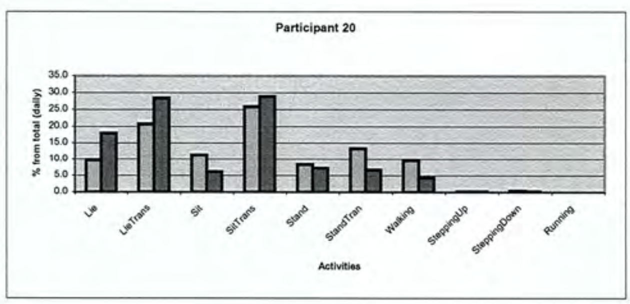

Participant 15
% from total (daily)
Lie
LieTrans
Sit
SitTrans
Stand
StandTran
Walking
SteppingUp
SteppingDown
Running
Activities


Participant 16
% from total (daily)
Lie
LieTrans
Sit
SitTrans
Stand
StandTran
Walking
SteppingUp
SteppingDown
Running
Activities


Participant 17
% from total (daily)
Lie
LieTrans
Sit
SitTrans
Stand
StandTran
Walking
SteppingUp
SteppingDown
Running
Activities


Participant 18
% from total (daily)
Lie
LieTrans
Sit
SitTrans
Stand
StandTran
Walking
SteppingUp
SteppingDown
Running
Activities


Participant 19
% from total (daily)
Lie
LieTrans
Sit
SitTrans
Stand
StandTran
Walking
SteppingUp
SteppingDown
Running
Activities


Participant 20
% from total (daily)
Lie
LieTrans
Sit
SitTrans
Stand
StandTran
Walking
SteppingUp
SteppingDown
Running
Activities